TRIO, AN EXPERT SYSTEM FOR AIR INTERCEPT TRAINING

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ABSTRACT

TRIO is an expert system for training F-14 interceptor radar operators in the basic tactics of high speed air intercepts. It introduces artificial intelligence methods into real-time training. The TRIO task environment supports simulations of airborne radars, interceptor and target aircraft, and weapons models. It provides dynamic displays of heading, bearing, and displacement vectors, radar screens, flight instruments, intercept parameters, missile envelopes and interceptor/target aircraft ground tracks. It incorporates real-time speech recognition and synthesis subsystems including highly advanced capabilities for recognition of naturally articulated, extended utterances. TRIO supports three instructional modes: pre-flight demonstrations, in-flight monitoring and guidance, and post-flight debriefing. The instruction employs an articulate expert to demonstrate and explain intercept tactics, a set of daemons for real-time performance monitoring, and a knowledge-based performance analysis program to detect and diagnose student errors. TRIO is currently implemented on a personal LISP machine, the BBN Jericho computer.

INTRODUCTION

TRIO is an expert system for training F-14 radar intercept officers (RIOs) in basic air intercept tactics. Like most expert systems, TRIO's knowledge base is derived from human experts and its conditional decisions are expressed *in the form of rules*. TRIO, however, addresses a *real-time* task and its rules prescribe *goal-oriented* behaviors. The TRIO system also introduces an effective facility for real-time recognition of natural speech. In the next sections we describe the basic intercept task of the F-14 RIO We then give an overview of TRIO and discuss TRIO's AI methods and training modes.

THE RADAR INTERCEPT TASK

The radar intercept officer sits in the rear seat of the F-14 aircraft He watches a radar display showing the enemy aircraft (called the *bogey*) and tells the pilot how to maneuver to intercept it The F-14 carries long-, medium-, and *short-range* missiles To be effective, each type of missile must be fired within its own optimum range and angle The RIO must learn how to plan an intercept as a coordinated series of missile attacks.

To have his fighter in the right positions at the right times to fire the different missiles, the RIO must do some complicated geometry in his head Here's how it works. An intercept is directed against an enemy aircraft, the bogey, by the RIO's aircraft, the fighter (see Fig. 1). The line between the two aircraft, called the *bogey bearing*, together with the two aircraft heading vectors, completes what is called the *intercept triangle*. The *Target Aspect*, TA is the angle between the bogey bearing and bogey heading. The *Lateral Displacement*, LD, is the perpendicular distance from the fighter to the bogey heading vector

During an engagement this triangle changes dynamically TA and LD are the key intercept parameters. Normally, both of these parameters are changing constantly, although there are certain headings that will hold one or the other constant The primary task for the RIO during the initial phase of the attack, is to achieve optimal values for both the TA and LD. Not only are both parameters normally changing, but clearly each is a function of

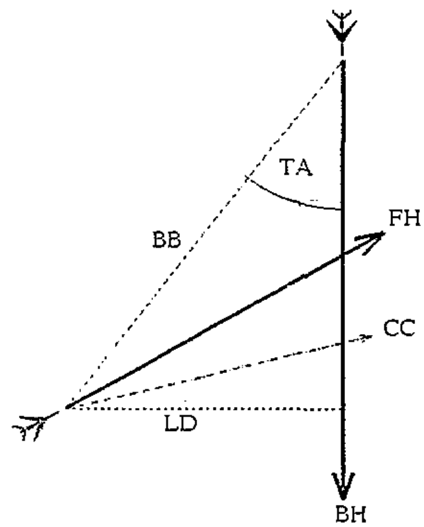

Figure 1: Intercept Triangle Geometry

the other [1]

A standard intercept tactic is called a *gouge*. An intercept engagement typically begins with ground control identification of a bogey which might be acquired about 60 miles away from the fighter. If the situation permits, the fighter fires the long-range missile His goals then are, first to achieve an optimum position for the medium-range attack, and then to fly a precise turn to position for the short range attack. The gouge calls for two difficult maneuvers. First, to get into an optimal angle (TA) for firing the weapon, normally 30 degrees, while simultaneously attaining an LD of 30,000 feet. To the RIO trainee this can be difficult for a number of reasons

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[1] On board the aircraft the RIO must estimate the LD, whereas the TA appears on the digital radar screen. The approximation formula taught is: LD = TA x RANGE x 100, which converts Range in nautical miles to LD in feet of displacement. The exact correspondence is: LD = RANGE x sin(TA).

- The dynamically changing situation is viewed through a radar scope. The radar picture must be interpreted quickly and accurately. This task often confuses and disorients novices.
- The entire intercept takes about three minutes. Because of the speed with which it develops, the RIO must plan ahead to "stay on top of the situation," anticipating his next action and allowing for contingencies
- The bogey must be kept within the radar angle at all times as breaking radar-lock can often be fatal, this restricts the fighter's maneuverability latitude;
- The position of the fighter's carrier as well as other bogeys in the area must constantly be kept in mind
- The RIO must calculate LD and estimate other intercept parameters "in his head" with dispatch.

After positioning and firing the medium range missile, at approximately 8 miles, the fighter must fly a precision turn that puts him directly behind the bogey at very close range (about 1 mile). This maneuver begins at a closing speed of approximately mach 2. It may involve strenuous g forces, and must be very carefully timed.

THE TRIO TASK ENVIRONMENT

TRIO supports simulations of aircraft radar flight dynamics and control, and missile weapons models. It generates dynamic displays of the intercept triangle, the interceptor's radar screens and flight instruments, and ground tracks of the fighter and bogey aircraft.

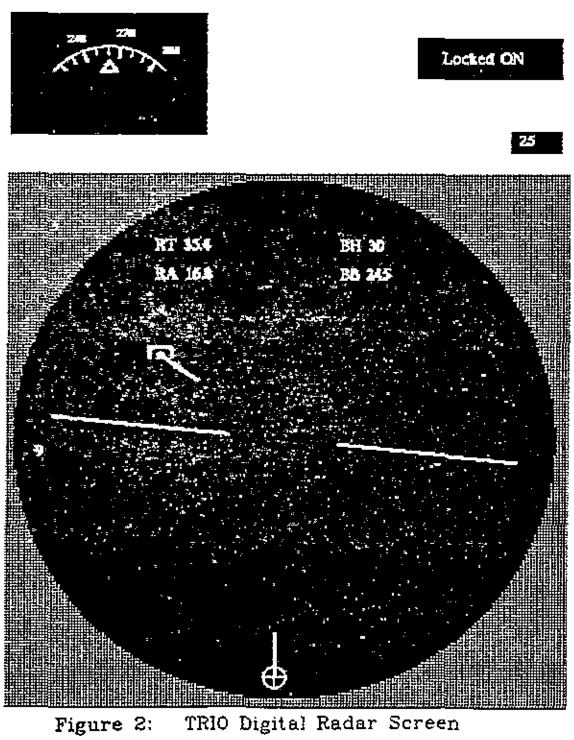

Figure 2: TRIO Digital Radar Screen

Figure 2 is a TRIO display of the digital radar screen. Parameter values for right target aspect (RT), range (RA), bogey heading (BH), and bogey bearing (BB) are shown. The icon at the upper left of the screen depicts the bogey, the vector emanating from the icon indicates the bogey s heading and speed. The icon at the bottom depicts the fighter with its velocity vector. The radial line shows the interceptor's wing attitude.

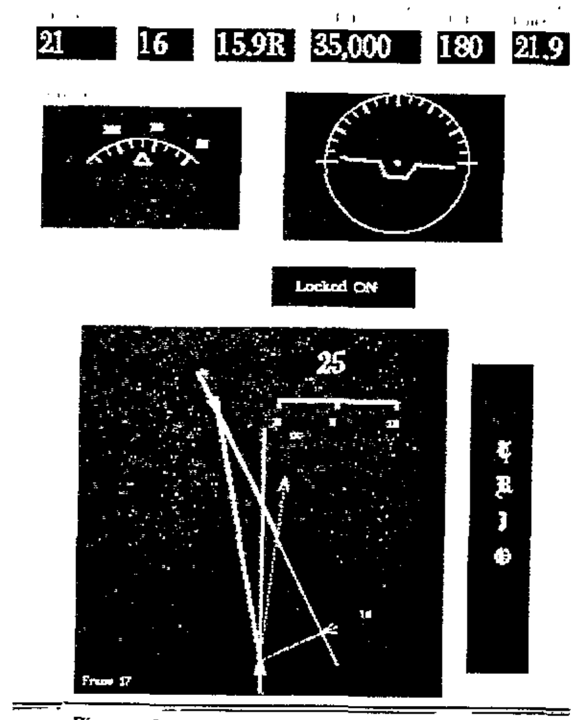

Figure 3: TRIO Parameter Display

Figure 3 is a TRIO display showing the compass and flight attitude indicator instruments, the radar lock status (i.e., locked ON or lock BROKEN), key intercept parameters and the intercept triangle.

Figure 4 is a TRIO ground track display that shows a bird's-eye view of the action. The lower track depicts the fighter's path. The upper track depicts the bogey's path. The pentagon icon depicts the fighter's aircraft carrier.

TRIO also supports real-time systems providing speech synthesis and continuous-speech recognition. The former is used by the TRIO articulate expert program to give spoken directions and explanations to a student. The recognition system lets the student speak to the pilot simulation program exactly as he would speak to a pilot. The TRIO speech recognition system can handle naturally spoken utterances described by relatively complex grammars.

Figure 5 shows the TRIO grammar describing the RIO heading commands The system can recognize utterances as terse as "steady up" and as verbose as "come starboard hard as possible to a heading of one four zero degrees."

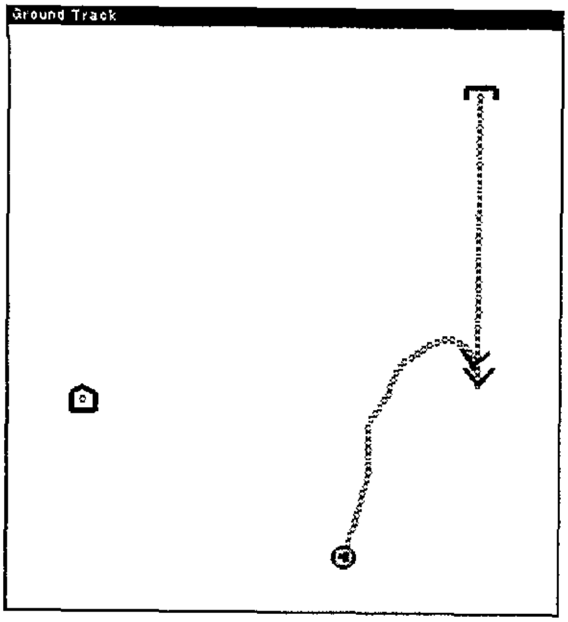

Figure 4: TRIO Ground Track Display

TRAINING MODES

TRIO provides training facilities for three distinct instructional functions demonstration, practice, and debriefing In demonstration mode, *TRIO* uses a program called an *articulate expert* "Expert" means that the program knows how to perform intercepts. "Articulate" means that the program can explain its performance in plain spoken English The program demonstrates the application of a gouge by performing an intercept and explaining its actions along the way. The intercept problem can be set up (either by the student or by the expert) through specifying initial parameter values of Bearing, Range, Altitude, Speed, and Heading (BRASH) for the fighter and bogey.

During initial phases of training, the bogey is programmed to fly a steady course. After the student learns the basic gouge, TRIO demonstrates *intercept tactics used* against a maneuvering bogey. Also, the student can fly the bogey to observe the tactics used by the expert.

During demonstration mode, the student watches a series of animated displays, both color and monochrome, depicting all flight instruments, a "ground track" (or bird's eye view of the two aircraft paths), and the intercept triangle. TRIO flies the run, issuing all appropriate *commands to the* (simulated) pilot. These commands appear visually in the command window of the multiple display configuration. Further, as each decision is made by the expert, the rationale for that decision is spoken by a *text-to-speech synthesizer*.

After seeing the expert program demonstrate a new tactic, students can use TRIO's practice facility to try it on their own. In practice mode, the student must use a radar screen similar to the one on board the aircraft, he does not have available the intercept triangle or ground track displays. He sees the digital radar screen (Figure 2) containing an artificial horizon (indicating wing attitude); a bogey symbol at appropriate range and azimuth position, vectors denoting the speed and headings of the two aircraft, and flight instruments indicating compass heading, bogey heading, TA, range, altitude, bearing, radar range and radar lock. He *directs the* intercept with voice commands spoken into a microphone connected to a voice recognition and semantic interpreter program.

After a practice run TRIO's expert program evaluates the student. At the start of debriefing mode, the program silently analyzes the run to find out how well the student's performance *corresponded* to the gouge. Then it plays back the run and discusses it with the student. It uses the ground track and radar displays as a reference, identifying points at which errors or inefficiencies were detected. *The program determines the* significant features of the student s performance preceding each

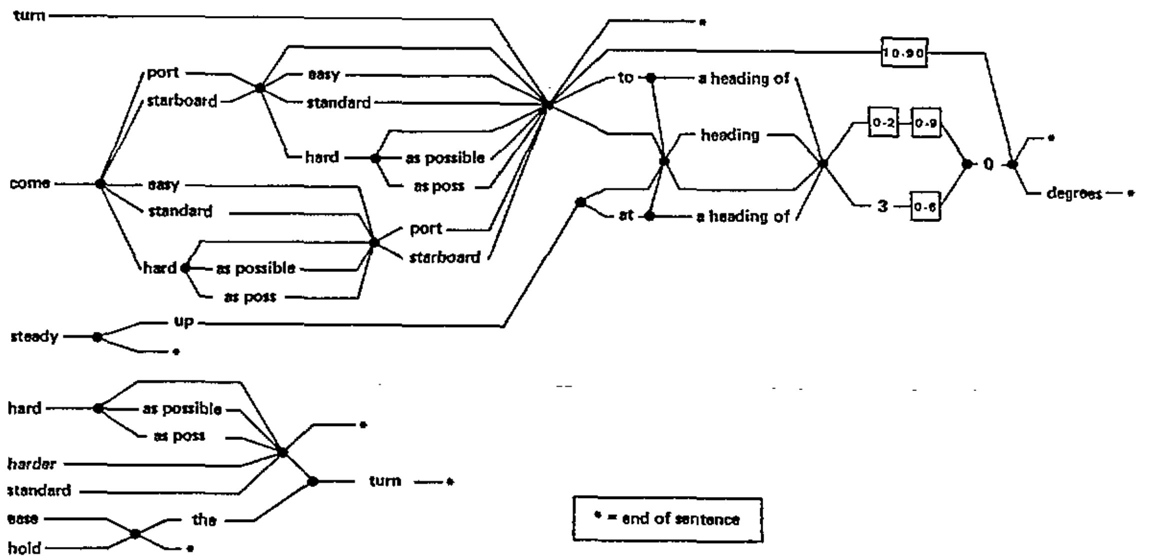

Figure 5: TRIO Command Grammar

error, for example, the specific actions or omissions that critically impaired a successful attack. Its analytic comments are spoken using the speech synthesizer.

AI METHODS

The major AI component of TRIO is its articulate expert. The expert is designed as the integration of a production rule system with a goal-oriented (means-ends-analysis) problem solver. This is realized by production rules whose right-hand-sides can either establish goals to be worked on, or add new rules to the rule-set. The goals, in turn, can establish more goals and/or more rules. Each goal has several components. These include.

- An action to be taken,
- A criterion for knowing that the goal has been achieved,
- An action to be taken when the goal is achieved (either next goal or next rule-set);
- A maintenance function to ensure that the initial action follows through,
- And a rationale for why the goal was established and what its high level purpose is

To illustrate the interaction of rules and goals, consider the following rule.

```
[LD < desired_LD] ==> [UseRuleSet Work_On_TA]
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where Work_On_TA consists of the following three rules

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{[TA ~ desired_TA] ==> [MakeGoal GOTO_COLLISION];

[TA < desired_TA] ==> [UseRuleSet TA_Too_Small];

[TA > desired_TA] ==> [UseRuleSet TA_Too_Big]}
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The two RuleSets named above are as follows.

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TA_Too_Small = {T ==> [MakeGoal GOTO_NOSE]}

TA_Too_Big = {T ==> [MakeGoal TURN_PAST_COLLISION]}
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This interplay between conventional production rules and goals has proved effective in capturing the tactical doctrine elicted from expert RIO instructors.

TRIO's ability to critique a student is based on the goal-oriented behavior of the expert. A typical student run takes approximately 200 to 400 simulated frames (each frame represents 1/2 second of real time). These frames are used to index a matrix of data points. The goals are used to specify a quantitative set of objectives, both disjunctively and conjunctively, thereby imposing a metric on the matrix of data points. Given a goal, a simple computation which can be done in real time determines if the goal is being worked on or not, and whether the goal is achieved in an optimal or an inefficient way. TRIO also includes a daemon facility Daemons can be used to monitor a student's performance during a practice run, and to alert him if critical events occur, e.g., the fighter is getting outside of missile envelope

TRIO is currently implemented in Interlisp on the BBN Jericho computer. Continued development of the system, leading to a prototype trainer, is planned

ACKNOWLEDGEMENTS

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